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The impact of resistance training on strength and correlates of physical activity in youth

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ABSTRACT
Resistance training (RT) may have a positive impact on specific correlates of physical activity (PA) in inactive and/or obese youth, with strength as a possible underlying mechanism. The aim of this study was to investigate this. Twelve participants (aged 8.9 ± 1.0 years) were assigned to an experimental group (EG) or control group (CG). Pre and post intervention assessments for strength, physical self-perceptions (PSPs), weight status, fundamental movement skills (FMS), and PA levels were completed. The EG participated in a twice-weekly 10-week RT programme. There were significant group x time interactions for FMS (CAMSA total P = 0.016, CAMSA skill score P = 0.036) and stretch stature (P = 0.002) (EG larges changes than the CG). Large effect sizes for the differences in change scores between the EG and CG were evident for CAMSA total score (Hedges' g = 0.830, P = 0.138), CAMSA skill score (Hedges' g = 0.895, P = 0.112) and relative strength (Hedges' g = 0.825, P = 0.140). This study demonstrated that a 10-week RT intervention has a positive effect on strength and FMS, and may also benefit weight status and PSPs. This study supports the development of RT interventions to develop these correlates, and increase PA levels.

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KEYWORDS
Strength; health; children; active; movement; obesity

Introduction

The positive effects of physical activity (PA) on the health and well-being of youth are well established with recent reviews stating that appropriate levels of PA reduces the risk of several diseases (e.g., diabetes and cardiovascular disease) and contributes to the development of healthy musculoskeletal tissues, the cardiovascular system and neuromuscular awareness (Chief Medical Office, 2019). Regular participation has the potential to improve a child's emotional, social and cognitive well-being, as well as health and physical fitness (Faigenbaum et al., 2014).

One of the key identified consequences of not being sufficiently active is the increased chance of obesity; childhood obesity is associated with a higher chance of obesity, premature death and disability in adulthood (World Health Organization, 2020). In addition to increased future risks, obese children experience breathing difficulties, increased risk of fractures, hypertension, early markers of cardiovascular disease, insulin resistance and negative psychological effects (World Health Organization, 2020). The World Health Organisation (WHO) reported that 340 million youth worldwide aged 5–19 were overweight or obese in 2016 (World Health Organization, 2020) and in Scotland in 2019, 16% of children were identified as being at risk of obesity (McLean et al., 2020). Owing to the high risk of overweight youth becoming obese adults, Hills et al. reported that the engagement of youth in physical activity is a fundamental component in the prevention of obesity (Hills et al., 2011).

The current United Kingdom (UK) PA guidelines for youth aged 5–18 recommend moderate-to-vigorous intensity physical activity (MVPA) for an average of at least 60 minutes per day across the week (Chief Medical Office, 2019) and there should be a variety of types and intensities of PA to develop movement skills, muscular fitness, and bone strength (Chief Medical Office, 2019). There should also be minimal sedentary time (Chief Medical Office, 2019). However, despite these guidelines, one of the more recent global surveillance studies, the Health Behaviour in School-aged Children survey (HBSC), reported that across Europe and North America, less than 50% of young people were meeting the recommended MVPA recommendation (World Health Organization Regional Office for Europe, 2016). PA levels also demonstrate a decline with age; 25% of 11 year olds meeting the recommendations compared to just 16% of 15 year olds (World Health Organization Regional Office for Europe, 2016). This indicates that as children advance through adolescence, physical inactivity becomes ubiquitous.

Identifying the importance of strength and movement skills as part of the PA guidelines, Faigenbaum et al. stated that low levels of muscular strength and power (dynapenia) negatively impact physical, psychosocial, emotional, and behavioural factors that drive physical inactivity in youth (Faigenbaum et al., 2020), therefore, this implies that strength-based exercise or "resistance training" is an integral part of PA for youth.

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The National Strength and Conditioning Association (NSCA) and the United Kingdom Strength and Conditioning Association (UKSCA) have developed position statements emphasising why youth should engage in RT (Faigenbaum et al., 2009; Lloyd et al., 2014). Research indicates that appropriately designed, and well-supervised RT programmes can benefit youth of all ages, with children as young as 5 years of age making noticeable improvements in strength (Weltman et al., 1986). Specifically, RT provides an additional stimulus to the neural maturation taking place, resulting in further development compared to youth who do not take part in RT (Myers et al., 2017). Additionally, RT has numerous health benefits for youth and an appropriate programme has been shown to improve bone health (Fukunaga et al., 1992), decrease cardiovascular disease risk (Faigenbaum et al., 2009), decrease metabolic risk factors, improve body composition (Shaibi et al., 2006) and improve self-esteem (Goldfield et al., 2015). Motor skills (such as jumping, running, throwing) have also been shown to be improved in youths after a period of resistance training (Faigenbaum et al., 2009). The importance of RT as a mode of PA is clear due the associated health benefits and its inclusion in the PA guidelines. An additional advantage of RT could be a positive impact on MVPA, which is indirectly supported by the "Pediatric Inactivity Triad" (PIT) which proposes that low muscle strength (dynapenia) is associated with low levels of MVPA (Faigenbaum et al., 2018).

When considering if there is a direct impact of RT on PA levels, there are only two studies to date that have investigated the effect of RT on PA levels. They found significant increases in daily spontaneous PA in 10–14 year olds following a RT intervention (Eiholzer et al., 2010; Meinhardt et al., 2013). Meinhardt et al. included 102 children (42 girls 60 boys) who took part in a school-based resistance training programme (Meinhardt et al., 2013). There was a significant increase in daily spontaneous PA in the boys but not the girls. However, the age range spanned across different pubertal stages with most of the girls being pubertal in contrast to the boys who were mainly pre-pubertal. The difference in findings between sexes may therefore be due to an increase in sex hormone concentration and a resulting increase in muscle mass (Ford et al., 2011). It was also unclear whether the children were sufficiently active prior to the study, and it was not apparent if there were significant differences between the boys and girls at baseline (Meinhardt et al., 2013). In Eiholzer et al. 46 boys participated in the study from two local ice hockey teams which involved taking part in supervised resistance training (Eiholzer et al., 2010). They found a significant increase in PA compared to the control group, despite both experimental and control groups being competitive ice hockey players. Whilst promising, these studies only demonstrated significant findings in males and did not substantially explore the potential underlying mechanisms of the effect, although in both studies there were significant increases in strength. However, in the Meinhardt et al. study, increases in strength were identified in both the boys and girls, despite the girls not showing a significant increase in PA (Eiholzer et al., 2010; Meinhardt et al., 2013). Overall, these studies concluded that RT could be used as a strategy to increase PA levels, but further investigation is required to substantiate this effect, particularly in inactive individuals.

There is some evidence to support the association between RT and PA levels but there is no evidence that supports possible mediators of this association. RT has been shown to have a positive impact on weight status, fundamental movement skills (FMS) and "the self" and these outcomes are identified as being associated with PA (thus, correlates of PA) and therefore may be important mediators of a possible effect of RT on MVPA. Additionally, as RT has been found to increase strength in youth, it may be proposed that strength could be an underlying mechanism that could explain a positive effect of RT on the correlates of PA.

To investigate the association between weight status and PA, Strong et al. reviewed cross-sectional and longitudinal observational studies that concluded that youth of both sexes who participate in relatively high levels of physical activity have less adiposity than inactive youth (Strong et al., 2005). More recent studies have reported associations between weight status and PA (Fairclough et al., 2012; Ferrari et al., 2015; Kreuser et al., 2013). Considering specifically RT as a strategy to treat and/or prevent obesity, there are systematic reviews that have explored the impact of RT on weight status (Alberga et al., 2011; Benson et al., 2008; Dietz et al., 2012; Lee et al., 2019; Schranz et al., 2013a) and the rationale being that there could be an increase in skeletal muscle mass and resulting increase in basal metabolic rate (Smith et al., 2014). Investigating the impact of RT on weight status in youth, a recent meta-analysis reported statistically significant effect sizes for skinfolds (Hedges' $g = 0.274$, $P = 0.01$) and body fat percentage (Hedges' $g = 0.215$, $P = 0.007$) (Collins et al., 2018). However, the review highlighted that the evidence base is not strong with substantial variability among intervention design across 18 studies, and with just 44% of included studies classified as "strong". Furthermore, the majority of research investigates multi-component interventions, so it is difficult to isolate the effect of RT (Alberga et al., 2011; Schranz et al., 2013a).

A recognised complication for overweight children with regards to PA is that they have difficulty performing fundamental movement skills (FMS) (Goodway & Ruiz, A, 2003). Strong evidence has been reported for a positive association between FMS competency and PA in youth (S Logan et al., 2015; Lubans et al., 2010; Ramos Dos Santos et al., 2017). FMS are commonly categorised as locomotor (e.g., running, jumping), stability (e.g., balancing, twisting) and object control (throwing, catching, kicking) (Lubans et al., 2010) and could be described as "building blocks" of more complex movements (SW Logan et al., 2018). It has been suggested that if muscular strength and FMS are not enhanced early in life this may hamper a child's ability to participate in a variety of activities and sports in later life (Faigenbaum & Myer, 2012). The PIT model also alludes to an association between muscular strength and FMS (Faigenbaum et al., 2018). In support of this, there were statistically significant effects reported of RT on specific FMS in youth (vertical jump, squat jump, standing long jump, spring and throw) following a meta-analysis of 22 studies (Collins et al., 2019). Both functional (e.g., changes in motor unit coordination) and structural (e.g., muscular hypertrophy) adaptations as a result of RT might bring about changes in motor competency (Behringer et al., 2011), which may be linked to the development of FMS.

In addition to FMS, the PIT model also identifies that "physical illiteracy" also includes lack of confidence, and knowledge to move proficiently in a variety of physical activities (Faigenbaum et al., 2018). There is a consensus for an association between PA and constructs relating to "the self" (e.g., self-esteem, self-concept, physical self-perceptions) in youth (Ahn & Fedewa, 2011; Ekeland et al., 2005; Liu et al., 2015). Despite some limitations regarding methodological design, collectively these reviews provide convincing evidence of an association between PA and "the self". Furthermore, a previous systematic review investigated the impact of RT on "the self" in youth with reported statistically significant effect sizes for resistance training efficacy, perceived physical strength, physical self-worth, and global self-worth (Collins et al., 2019). Indirect support also comes from studies that demonstrate a positive association between muscular fitness and physical self-perceptions (Smith et al., 2014). For example, in a systematic review, Lubans et al. (Lubans & Cliff, 2011) reported evidence of an association between muscular fitness and physical self-perceptions (perceived physical performance and perceived sports competence), overall physical self-worth and global self-esteem in youth.

Hence, although there is evidence to support the effect of RT on these correlates of PA, the research is not substantial and warrants further investigation. Furthermore, it remains uncertain as to whether there is an effect of RT on PA levels, and whether this effect is mediated by weight status, FMS and "the self".

Therefore, the aim of this study was to investigate the impact of a RT intervention on strength, correlates of PA (weight status, FMS and "the self") and MVPA, in inactive or overweight/obese youth.

Methods

Ethics and recruitment

Institutional ethics committee approval was granted before the study commenced. Information leaflets were displayed on social media and sent out to nine local primary schools. Eligible participants were primary school students aged 8–10 years. This age group was targeted due to the participants being old enough to understand instruction but still being pre-adolescent (Faigenbaum et al., 2009), therefore reducing the chance of an increase in sex hormone concentration and a resulting increase in muscle mass (Ford et al., 2011). Participants were ineligible if they were currently engaged in regular RT or had extensive experience in RT. They were also ineligible if they had: a pathological condition or disability which affects movement (e.g., cerebral palsy or dyspraxia), a behavioural or neuropsychological condition (e.g., autism or attention deficit hyperactivity disorder) or a physical injury preventing testing or training. Participants were only included if they were classified as either overweight/obese (Reilly et al., 2010) (the cut-off points are described below) or did not meet the MVPA guidelines (Chief Medical Office, 2019) (defined as "inactive" in this study) as evaluated during the first assessment session. Informed written consent was provided by participants and parents.

Participants

Twelve participants (7 males, 5 females) were recruited. All participants were classified as "inactive" (World Health Organization, 2011) and/or were classified as overweight or obese (Reilly et al., 2010). The participants were quasi-randomly allocated to the experimental group (EG, 3 males, 3 females) or control group (CG, 4 males, 2 females) based on training day availability.

Procedure

Following completion of health questionnaires, baseline testing on all participants was conducted where strength, FMS, weight status and physical self-perceptions were assessed. All assessments were completed by trained research assistants. Measurements were completed on the same day, using the same instruments at each time point and in the same order. Participants completed the questionnaires before physical assessments to prevent the actual process of assessment influencing their responses. Following these sessions, accelerometers were provided to be worn for 7 days. Follow-up tests were subsequently completed the week following the intervention. Attendance was recorded and compliance calculated as the average number of sessions attended by all participants.

Assessments

Strength

An isometric mid-thigh pull (IMTP, custom-built rig, Pasco force plates) was used to assess peak force with a previously reported protocol involving a standardised warm up, standard set up position and maximal pull over two trials (Moeskops et al., 2018). The highest peak force in Newtons and peak force relative to body mass were used for analysis. Within- and between-session measures of absolute and relative peak force were previously reported to be reliable (CV ≤ 9.4%, ICC ≥ 0.87) (Moeskops et al., 2018).

Fundamental movement skills

To assess FMS, the Canadian Agility and Movement Skills Assessment (CAMSA) was conducted (Longmuir et al., 2017) with the time required to complete the course recorded and the quality of each skill scored as prescribed in a specified checklist (including items such as "body and feet are aligned sideways" and "correct step-hop foot pattern when skipping") (Longmuir et al., 2017). The total score was quantified as sum of skill and time scores. Evidence for test–retest reliability for completion time was excellent (ICC = 0.82–0.84) and for the skill score, it was moderate to substantial (ICC = 0.46–0.74) (Longmuir et al., 2017).

Weight status

Stretch stature (Seca Leicester stadiometer) and body mass (Seca 813) were assessed to the nearest 0.1 cm and 0.1 kg, respectively (International Society of Anthropometry and Kinanthropometry, 2011). Body Mass Index (BMI) was calculated and BMI Z-scores for age and gender (standard deviation score) which are measures of relative weight adjusted for child age and sex (Must & Anderson, 2006). This was calculated using the Cole LMS method and UK 1990 reference data based on 37,700 children, with an age range of 23 weeks gestation to 23 years (Cole et al., 1998). BMI-related weight status was classified as: healthy weight = BMI Z-score <1.04; overweight = BMI Z-score 1.04–1.63; obesity = BMI Z-score ≥1.64 (Reilly et al., 2010).

To assess body fatness, four skinfolds (tricep, bicep, subscapular and supraspinale) were taken by a Level 1 ISAK accredited anthropometrist, (International Society of Anthropometry and Kinanthropometry, 2011). This method has been used previously with children (Cicek et al., 2014). Girth measurements were also taken for the waist, hips, and right upper arm (International Society of Anthropometry and Kinanthropometry, 2011).

Physical Self-perceptions

The CY-PSPP (Whitehead, 1995) was used to assess the participants' physical self-perceptions. This test assesses six different dimensions of self-concept: sport competence, physical condition, body attractiveness, strength competence, physical self-worth, and global self-worth (Whitehead, 1995). This questionnaire has been validated with children aged between 8 and 12 years (Welk & Eklund, 2005). Perceived body attractiveness was not a key outcome measure and was removed from the questionnaire.

Physical activity

PA was monitored with an ActiGraph GT3X+ accelerometer for 7 days before and after the intervention. Accelerometers were set to record at a 30 Hz sampling frequency (Yang & Hsu, 2010). Participants were instructed to wear the monitor at all time times on the right hip, except during water-submerged activities, during contact sports, or during sleep. Raw data was downloaded on the ActiLife 6.1 software as activity counts at 10 second intervals. Valid wear time was defined as a minimum of 4 full days of recorded accelerometer data (including at least 1 weekend day), with a full day consisting of a total 10 hour wear time (Ward et al., 2005). A 60-s epoch was used and non-wear time was defined as strings of consecutive zeros lasting 60 min or more (Cooper et al., 2015). The accelerometer output is in counts per minute (cpm). Evenson cut points (Evenson et al., 2008) were used to define time spent being sedentary (≤100 cpm) and time spent in MVPA (≥2296 cpm). Extra activity was recorded via a physical activity diary, including estimated intensity of the activity, and additional MVPA minutes were added for participants who had performed activities while not wearing the accelerometer (e.g., swimming).

Treatment conditions

The CG was asked to refrain from any RT and maintain their normal PA for the study period. The EG participated in a progressive RT programme delivered after school at the University of Dundee twice a week for 10 weeks in addition to their normal activity. Qualified strength and conditioning coaches delivered the sessions, with a coach to participant ratio of 1:3. The session content is shown in Table 1. The range of sets and reps followed recommendation by the UKSCA for a youth beginner (Lloyd et al., 2014) and a warm up and cool down was completed (Faigenbaum et al., 2009). The participants initially were to complete eight repetitions but as the loading increased, this was reduced to 6. There were four key exercises (Table 1) with variable core strength exercises and a "hanging challenge" to finish. The use of body weight and free weights were included as they provide a full-body movement to challenge major muscle groups and control of body mass in a variety of push, pull, squat and lunge movements to develop foundational strength (Kraemer & Fleck, 2005). The exercises outside of the key exercises were varied and were sometimes a choice of the participant to encourage engagement. Rest between sets and exercises was 60 to 120 seconds (Faigenbaum et al., 2009) and the initial load was the lightest available (broomstick or 5 kg bar (with 2.5 kg plates for deadlifts)). This load progressed by 5–10% once the coach deemed the participant competent at the exercise and the load appeared insufficient to provide overload (Faigenbaum et al., 2009). Load progression during the intervention was recorded. The session duration was 45 minutes.

Table 1. Resistance training programme.

Exercise	Sets/Reps
Warm up – a variety of active games, overhead broom stick squat (plus 1 warm up set of each exercise)	5 minutes
Key exercise 1- Deadlift	2 x 6–8
Key exercise 2- Push Press/TRX row	2 x 6–8 (alternate push/ pull each session)
Key exercise 3- Back Squat	2 x 6–8
Key exercise 4- Walking lunge/overhead lunge/side lunge	2 x 6–8 (each leg)
Front plank/dead bugs/hollow hold	Variable depending on the exercise.
Hanging challenge – hang from a pull up bar.	Maximum hang time
Cool down – stretch of major muscle groups	5 minutes

Feedback session

A feedback session was conducted and recorded with the parents (n = 5) and children (n = 5) from the EG, following the intervention. The key theme explored was whether the parents and the children felt there were benefits (to the child) from taking part in the intervention.

Data analysis

Data analysis for the quantitative measures was undertaken using the Statistical Package for the Social Sciences (SPSS, version 22, SPSS Inc., Chicago, Ill, USA) with differences between treatment groups being considered statistically significant at $P < 0.05$. All data were assessed for normality and were analysed accordingly. Differences between groups at baseline were tested using independent samples t-tests. A mixed ANOVA with repeated measures was conducted to examine the effect of the intervention between groups, over time. Hedges' g was used to assess the differences in changes scores between the EG and CG (pre and post intervention). Effect sizes were defined as small (0.20–0.49), medium (0.50–0.79) and large (>0.80) (Cohen, 1988). All data are presented as mean (±sd). Recommended sample sizes were calculated using G-Power following the primary analyses to determine the sample size required to detect the effect at the chosen significance level (Faul et al., 2007)

Results

Table 2 shows the baseline characteristics of the sample. The age of the sample was 8.9 ± 1.0 years. All participants were classified as either overweight/obese (n = 11) and/or inactive (n = 10), noting that there was not sufficient wear time for two of the participants to assess activity levels (although they were both classified as overweight/obese). Mean sessions attended was 79% (ranging from 70% to 90%) and, removing missed sessions due to school holidays (4 sessions), the mean attendance was 93% (ranging from 90% to 100%). None of the participants withdrew from the study. There were no reported training injuries or excessive muscle soreness at any stage. There were no significant differences between the groups at baseline across all measures (Table 2).

Table 3 shows the pre and post-intervention data for all outcomes for the EG and CG alongside the ANOVA data and associated effect sizes. Although baseline measures of MVPA were collected, statistical analysis was not possible as only data from three participants in each group was obtained.

Intervention effects

All data were normally distributed. From the ANOVA analysis, the significant main effects for time were: CAMSA total (P = 0.002), CAMSA skill (P = 0.036), CAMSA time (P = 0.005), stretch stature (P < 0.001), and body mass (P = 0.004). The significant main effects for group were: BMI (P = 0.048), BMI Z-score (P = 0.046) and hip circumference (P = 0.048). There were significant time x group interactions for CAMSA total (P = 0.016), CAMSA skill score (P = 0.036) and stretch stature (P = 0.002) with the EG displaying larger changes than the CG. This demonstrated a positive impact of the RT intervention on FMS.

While not statistically significant, there were large, positive effect sizes for CAMSA total score (Hedges' g = 0.830, P = 0.138), CAMSA skill score (Hedges' g = 0.895, P = 0.112) and relative strength (Hedges' g = 0.825, P = 0.140). There was a medium positive effect size for arm circumference (a decrease in the EG but an increase in the CG) (Hedges' g = 0.500, P = 0.357). All other effect sizes were negligible or small. A post hoc power analysis revealed that an n of between 4 and 70 (on outcomes where an effect size of ≥0.2 was evident) would be needed to obtain statistical power at the recommended 0.80 level (Cohen, 1988).

Table 2. Baseline characteristics.

Variable	Experimental Group (n = 6) (mean±sd)	Control Group (n = 6) (mean±sd)
Age (yrs)	8.7 ± 1	9.2 ± 1
Males (n)	3	4
Females (n)	3	2
Stretch stature (cm)	143.3 ± 5.3	140.8 ± 5.8
Body mass (kg)	50.5 ± 11.2	40.3 ± 6.4
BMI (kg/m^2)	24.4 ± 4.0	20.3 ± 2.5
BMI Z-score	2.54 ± 0.61	1.50 ± 0.93
Overweight (n)	0	2 (33%)
Obese (n)	6 (100%)	3 (50%)
Inactive (n)	5 (100%)	5 (100%)
Average daily MVPA (mins)	38.2 ± 11.6 (n = 5)	37.9 ± 6.6 (n = 5)

Note – baseline physical activity data was collected from 10 out of 12 participants. No statistically significant differences between groups (P < 0.05).

Feedback session

Children and parents expressed positive changes with regard to „the self" including: feeling positive to keep progressing, improved confidence and a sense of achievement. Additionally, comments were made that might support an impact of RT on PA levels with one child stating that they were encouraged to try other activities and another child identifying that they had gained strength which had made running easier.

Discussion

The aim of this study was to investigate the impact of RT on strength, correlates of PA (weight status, FMS and "the self") and MVPA. There was a statistically significant interaction for group x time for the FMS outcomes of CAMSA skill score, and total score, with large effect sizes for some FMS outcomes. There were also small to large effect sizes for strength, a medium effect size for weight status and small effect sizes for physical self-perceptions. There were no statistically significant findings for all other outcomes and there were not sufficient data to assess the impact on MVPA. This pilot study shows that there are positive effects of RT on specific correlates of PA in youth and potentially also on strength, although further research would be required to substantiate this. Therefore, in part, these findings support the UKSCA (Lloyd et al., 2014) and NSCA's (Faigenbaum et al., 2009) position statements on youth RT that both report that RT may have a positive impact on strength, weight status, FMS and "the self".

Strength

There was a large positive effect size found for relative strength (g = 0.825, P = 0.140) and a small, positive effect size for maximum strength (g = 0.329, P = 0.540) although these were not statistically significant. Importantly for an overweight/obese population, an improvement in strength promotes engagement in daily activities, physical activity and subsequently improves their health-related quality of life (Thivel et al., 2016). Therefore, an increase in relative strength is an important outcome for this participant group and the large effect size is a key finding.

Previous studies have shown an increase in strength following a RT intervention in overweight and obese youth (Alberga et al., 2011; Schranz et al., 2013b) despite variable protocols used to measure strength and inconsistent intervention design. An improvement in strength, particularly in prepubescent participants, has been attributed to neural factors rather than hypertrophy (Granacher et al., 2011) which is in support of the PIT model regarding the association between strength and FMS (Faigenbaum et al., 2018) and additionally could explain the FMS findings in the present study, which are detailed below.

Table 3. Changes in outcomes for EG and CG pre and post intervention.

	EG (n = 6) mean±sd (range)			CG (n = 6) mean±sd (range)			Effects (group x time)		
Outcome	Pre	Post	Change	Pre	Post	Change	F	P	Effect size (Hedges' g)
The Self									
CY-PSPP total score	88.8 ± 16.5 (57.0–101.0)	89.7 ± 10.0 (72.0–103.0)	0.8 ± 8.4	90.5 ± 22.0 (60.0–120.0)	91.8 ± 17.9 (74.0–120.0)	1.3 ± 6.8	0.011	0.919	0.031
Perceived strength	19.8 ± 2.9 (17.0–24.0)	19.2 ± 3.8 (16.0–24.0)	−0.7 ± 0.9	18.5 ± 6.1 (9.0–24.0)	18.8 ± 4.7 (12.0–24.0)	0.3 ± 2.8	0.570	0.468	−0.214
Physical self-worth	20.0 ± 4.5 (12.0–24.0)	19.8 ± 2.7 (16.0–24.0)	−1.2 ± 3.1	18.8 ± 5.4 (12.0–24.0)	18.5 ± 4.7 (12.0–24.0)	−0.3 ± 2.1	0.254	0.625	−0.201
Global self-worth	18.2 ± 4.7 (9.0–22.0)	20.0 ± 3.0 (15.0–23.0)	1.8 ± 3.3	20.3 ± 4.7 (12.0–24.0)	21.0 ± 5.1 (11.0–24.0)	0.2 ± 0.7	1.196	0.300	0.367
Sport competence	15.3 ± 3.4 (11.0–19.0)	15.5 ± 4.0 (10.0–19.0)	0.2 ± 1.1	16.5 ± 6.1 (8.0–24.0)	18.3 ± 4.8 (12.0–24.0)	1.8 ± 2.0	2.809	0.125	−0.345
Physical condition	15.5 ± 4.8 (7.0–21.0)	16.2 ± 3 (10.0–20.0)	0.7 ± 4.5	15.8 ± 6.2 (9.0–24.0)	15.2 ± 5.3 (10.0–24.0)	−0.7 ± 4.8	0.206	0.659	0.275
FMS									
CAMSA total score	13.2 ± 4.2 (9.0–19.0)	17.0 ± 4.2 (12.0–22.0)	3.8 ± 1.1	16.8 ± 3.1 (14.0–22.0)	17.5 ± 2.6 (14.0–20.0)	0.7 ± 2.2	8.318	0.016*	0.830
CAMSA time score	4.2 ± 2.9 (1.0–9.0)	6.5 ± 2.9 (3.0–10.0)	2.3 ± 1.1	7.5 ± 2.1 (5.0–11.0)	8 ± 2.1 (6.0–10.0)	1.0 ± 1.7	2.105	0.177	0.498
CAMSA skill score	9.5 ± 1.9 (7.0–12.0)	11.0 ± 1.8 (8.0–13.0)	1.5 ± 0.8	10.0 ± 0.9 (9.0–11.0)	10.0 ± 1.3 (9.0–12.0)	0.0 ± 1.1	5.870	0.036*	0.895
Weight status									
Stretch stature (cm)	143.3 ± 5.3 (138.4–150.4)	145.5 ± 5.5 (140.3–153.2)	2.2 ± 0.3	140.8 ± 5.8 (132.5–147.1)	142.0 ± 6.1 (133–148.9)	1.3 ± 0.4	16.696	0.002*	0.150
Body mass (kg)	50.5 ± 11.2 (40.4–71.2)	51.8 ± 10.7 (42.5–71.7)	1.3 ± 0.8	40.3 ± 6.4 (29.4–47.9)	41.0 ± 6.4 (29.7–47.1)	0.8 ± 0.9	0.863	0.375	0.056
BMI (kg/m^2)	24.4 ± 4.0 (21.5–31.6)	24.3 ± 3.5 (21.4–30.6)	−0.1 ± 0.6	20.3 ± 2.5 (15.9–23.5)	20.2 ± 2.4 (15.6–22.3)	−0.1 ± 0.5	0.045	0.837	0.025
BMI Z-score	2.54 ± 0.61 (2.09–3.70)	2.49 ± 0.56 (2.03–3.58)	−0.04 ± 0.09	1.50 ± 0.93 (−0.24–2.36)	1.47 ± 0.93 (−0.38–2.19)	−0.0 ± 0.1	0.010	0.921	−0.024
Skinfolds (mm)	89.6 ± 21.8 (66.0–122.4)	86.0 ± 17.6 (68.1–108.0)	−3.7 ± 7.0	65.2 ± 22.6 (28.0–95.4)	65.4 ± 21.4 (26.4–89.0)	0.0 ± 4.9	0.917	0.361	0.169
Waist circumference (cm)	80.8 ± 11.8 (68.0–103.0)	80.4 ± 9.9 (72.0–100.0)	−0.3 ± 2.4	69.2 ± 5.2 (60.2–75.5)	70.0 ± 4.5 (57.5–75.0)	0.8 ± 1.8	0.665	0.434	0.122
Hip circumference (cm)	90.3 ± 7.3 (83.0–103.0)	90.4 ± 7.8 (83.0–104.5)	0.2 ± 1.7	81.0 ± 6.7 (70.0–88.0)	81.4 ± 6.4 (69.5 − 86.5)	0.4 ± 1.6	0.037	0.851	0.026
Arm circumference (cm)	26.7 ± 2.4 (23.0–30.2)	26.4 ± 1.9 (23.4–28.5)	−0.3 ± 0.9	23.4 ± 2.8 (19.0–27.8)	24.4 ± 2.8 (19.5–27.5)	1.0 ± 1.3	3.257	0.101	0.500
Strength									
Maximal strength (N)	1007.8 ± 255.7 (737.0–1455.0)	1088.7 ± 263.2 (812.0–1471.0)	80.8 ± 67.6	862.7 ± 118.8 (675.0–975.0)	872.2 ± 104.5 (710.0–998.0)	9.5 ± 74.8	2.501	0.145	0.329
Relative strength (N. kg^{-2})	19.9 ± 1.4 (18.0–22.0)	21.0 ± 2.3 (19.0–25.0)	1.1 ± 1.3	21.7 ± 2.9 (18.0–26.0)	20.9 ± 1.9 (19.0–24.0)	−0.8 ± 3.0	1.605	0.234	0.825
MVPA									
Average daily MVPA (mins)	38.2 ± 11.6 (30-54)	37.3 ± 13.4 (22-47) (n=3)	-4.7 ± 4.9	37.9 ± 6.6 (30-46)	30.3 ± 10.0 (19-38) (n=3)	-6.6 ± 4.6	/	/	/

* = P < 0.05
Hedges' g = the difference in change scores between the EG and CG (pre and post intervention).
Abbreviations: CY-PSPP = Children and Youth Physical Self-Perception Profile, CAMSA = Canadian Agility and Movement Skills Assessment

FMS

CAMSA skill and total scores significantly increased in the EG in comparison to the CG over time (P = 0.036 and P = 0,016 respectively), although this was not the case for CAMSA time score. It is important to note that time score did not decrease so the participants did not compromise the speed of movement for quality. When examining the effect sizes, there was also found to be a large effect of the intervention on the CAMSA skill score (g = 0.895) and the total score (g = 0.830) (although time score is accounted for in the total score). An explanation for these positive findings could be that neural adaptations (changes in motor unit coordination, firing and recruitment) occurred as a result of RT (Ozmun et al., 1994), and since they are essential for optimal movement, were manifested in changes in FMS. This also supports the hypothesis that strength could be an underlying mechanism that would explain the change in FMS, due to the increase in relative strength.

Our current findings suggest that RT has a positive effect on "process outcomes" of FMS (i.e., skill score), which as far as we are aware has not been previously evaluated in the literature. This would imply that a RT intervention has a positive impact on the quality of movement. Improved FMS competence is thought to accompany increased PA (Stodden et al., 2008) and recent research has reported associations between process assessments of FMS and PA levels (Logan et al., 2015; Ramos Dos Santos et al., 2017). Therefore, if RT has a positive impact on FMS as is suggested by the current study, it is hypothesised that this could have a positive effect on PA levels, however, further work is needed to substantiate this.

Weight status

The statistically significant positive changes over time for stretch stature (P < 0.001), and body mass (P = 0.004) is a logical finding due to maturation. The statistically significant changes in stretch stature in the EG, in comparison to the CG over time (P = 0.002) may have an influence on the group differences in BMI and BMI Z-score, however, effect sizes were negligible. Despite no statistically significant changes in weight status outcomes in the EG, in comparison to the CG, over time the medium-positive effect size for arm circumference (g = 0.500) is difficult to interpret due to no significant changes in skinfolds. This finding could possibly be due to an increase in skeletal muscle mass and resulting increase in basal metabolic rate (Smith et al., 2014). However, there is mixed evidence with regards to whether youth may experience increases in muscle mass following RT, most likely due to inadequate levels of circulating testosterone (Faigenbaum et al., 2009); this may explain why there were no effects on the majority of weight status outcomes in the present study. Additionally, taking part in an active intervention was not sufficient to increase overall energy expenditure to elicit a change in weight status outcomes. This emphasises the importance of including dietary measures in further research.

A previous study involving a similar population reported a significant decrease in body fat percentage and increase in lean body mass (McGuigan et al., 2009), which were findings not observed in the present study. However, there was a larger sample size, a DEXA scan was used as the measurement tool and the participants trained three times a week. Although overall the evidence to support a positive effect of RT on weight status is not compelling, there is some evidence from the findings to support a positive effect. Consequently, a larger scale study of longer duration would be recommended to investigate this in more depth, in particular as there is a trend of decreasing skinfolds measurements in the EG.

"The self"

There were no statistically significant changes in CY-PSPP score in the EG, in comparison to the CG. From the effect size data, there were small positive effect sizes for perceived physical condition (g = 0.275) and global self-worth (g = 0.367), but small negative effect sizes for perceived strength (g = −0.214), sport competence (g = −0.345) and physical self-worth (g = − 0.201). With negligible to small effect sizes, these findings are unlikely to represent an important change and additionally are in conflict with some of the feedback session comments. This might suggest that although the measurement tool was previously validated with a similar age group (Welk & Eklund, 2005), this might have had an impact on the findings due to reported developmental differences (Estevan & Barnett, 2018). Similar studies using the same assessment tool reported significant findings (Goldfield et al., 2015; Velez et al., 2010), which is in conflict with the findings of the current study. However, the participants were older, the studies involved larger sample sizes and the interventions were longer duration. Taking this into consideration, it is hypothesised that perceived physical competencies could develop through RT, ultimately enhancing global self-esteem, which is a mechanism explained in the EXSEM model (Sonstroem & Morgan, 1989).

Feedback session

While the feedback session was not part of the data reported herein, anecdotally, the researchers learned that, based on the comments from both parents and children, there are potential positive impacts on "the self" that may not have been evidenced in the questionnaire Future investigations should include specific qualitative methodologies to uncover these possibilities. These positive comments imply the possible sustainability of such a programme and are in agreement with a previous meta-analysis (Collins et al., 2019). A specific comment made regarding a child feeling confident enough to try other activities, also supports the hypothesis that the RT programme could indirectly impact on PA levels.

Limitations

The power analysis indicated that the study was adequately powered for the CAMSA total score and speed score (required n = 4 and 6, respectively), however, it was underpowered to detect small between group differences for many outcomes. This pilot study makes a unique contribution however by providing the effect sizes needed to inform a definitive RCT to investigate this topic further. Regarding recruitment, it could be difficult for parents to acknowledge that their child may be inactive and/or overweight/obese and therefore they may be less likely to see the need for their child to be involved (Jeffery et al., 2005). Hence, it may be beneficial to recruit via a clinical pathway for this population in future definitive RCT's.

Regarding the data, although not statistically different at baseline, there appears to be large differences between the groups for some of the measures and this should be acknowledged when interpreting the results. Specifically for the measure of "the self", it should be noted that questionnaires administered to youth may not be understood by the participants, particularly due to the young age (pre-adolescent) (Faigenbaum & Zaichkowsky, 1997) and therefore this may present a limitation for the current study. Additionally, future research should consider a measure of maturation status. Finally, unfortunately there was no sufficient post-intervention data collected for MVPA, and it is apparent that significant emphasis on the importance of sufficient wear time and clear instructions are crucial. However, research has reported the difficulties of compliance with accelerometer wear time in children (Robertson et al., 2011) but suggests some ways to increase this, such as rewards, social conformity and wear time reminders (McCann et al., 2016), which could be implemented in future studies to increase compliance.

Although the intervention was 10 weeks in duration, it took a significant amount of time for the children to learn the exercises and therefore a familiarisation period would be recommended. Additionally, while participants were asked to maintain their normal PA and dietary patterns over the study period, it is not possible to ascertain if this was the case. Our study did not include a long-term follow-up and it is therefore unknown whether any changes in outcomes persisted when the training stimulus was withdrawn, and longer-term studies are needed to determine if any benefits from RT are maintained, if the participants remain engaged and/or have increased PA levels.

Conclusion

In summary, this study demonstrated that a 10 week RT intervention has a positive effect on strength, and FMS. Effect sizes suggest there may also be an impact on weight status and "the self". Overall, this pilot study provides evidence to support the effectiveness and feasibility of RT as a mode of PA for overweight/obese and/or inactive youth. Furthermore, the study offers both guidance for future intervention design, for a full RCT, and programme delivery. To build on these findings, a larger scale study could provide useful evidence to support the development of RT interventions for inactive and/or overweight/obese children to not only develop the identified correlates of PA but ultimately increase PA levels and in the longer term have a positive effect on health and well-being.

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No potential conflict of interest was reported by the author(s).

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